SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

DTIC FILE COPY

Form Approved OMB No. 0704-0188

AD-A228 952

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution limited
	5. MONITORING ORGANIZATION REPORT NUMBER(S) AFOSR-TR- 90 1089
6a. NAME OF PERFORMING ORGANIZATION Georgia Institute of Technology	6b. OFFICE SYMBOL (If applicable)
7a. NAME OF MONITORING ORGANIZATION AFOSR /NM	
6c. ADDRESS (City, State, and ZIP Code) ISyE Georgia Institute of Technology Atlanta, GA 30332-0205	7b. ADDRESS (City, State, and ZIP Code) AFOSR/NM Bldg 410 Bolling AFB, DC 20332-6448
8a. NAME OF FUNDING/SPONSORING ORGANIZATION AFOSR	8b. OFFICE SYMBOL (If applicable) NM
9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER AFOSR 89-0407	
8c. ADDRESS (City, State, and ZIP Code) AFOSR/NM Bldg 410 Bolling AFB, DC 20332-6448	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
61102F	2304	A5	

11. TITLE (Include Security Classification)

Summary of Recent Research Accomplishments on "Stochastic Network Processes"

12. PERSONAL AUTHOR(S)

~~One~~ Richard Serfozo

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final report	FROM 5/1/89 TO 6/30/90		7

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report summarizes the research done on AFOSR Grant 89-0407 during the last year.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION
22a. NAME OF RESPONSIBLE INDIVIDUAL Dr. Jon A. Sjogren	22b. TELEPHONE (Include Area Code) (202) 767-4940 / 22c. OFFICE SYMBOL NM

Summary of Recent Research Accomplishments on
"Stochastic Network Processes"

by

Richard F. Serfozo
AFOSR Grant 89-0407

1. Introduction

The aim of ~~our~~ this research has been to develop stochastic network processes for modeling the movement of discrete units in networks. Primary examples are the movement of data packets in computer networks, the movement of parts and supplies in manufacturing plants or in military support systems, and the movement of smart cars and trucks on electronically monitored highways. The distinguishing feature of our research is the emphasis on the next generation of intelligent networks that will be the backbone of our computer, military and transportation systems. Most of the present theory of stochastic network processes is for unintelligent networks in which the nodes operate independently, the routes of units are independent and the units move one at a time. In an intelligent network, however, the processing at the nodes and the routing typically depend dynamically on the actual congestion, and units move concurrently. Examples of dependencies are routing units to avoid congested nodes, speeding up of processing as queues grow, splitting and merging of units, batch processing and distributed as parallel processing. Our general goal is to provide an understanding of intelligent networks by describing their stochastic behavior. The following is a summary of our major findings in the last two years.

2. Characterization of Flows in Networks

Considerable insight into a network is obtained by viewing the flows of units between pairs of nodes as a multivariate point process. A basic problem in this regard is to characterize such processes: when are they Poisson, compound Poisson, infinitely divisible etc. or when can they be approximated by such processes? Such information is useful for analyzing networks that are a pasting together of smaller networks with Poisson output flows.

A classical result proved by Burke and Reich in the late 1950's for the single M/M/1 service system is that the flow of units exiting the system is a Poisson process. A similar result was proved by several researchers in the late 1970's for the open Jackson network process: the flows of units exiting in the network from the respective nodes are independent Poisson processes. The approach for these results did not solve the problem of characterizing Poisson flows in intelligent networks with dependencies.

Using another approach, however, we were able to solve this problem for rather general network processes. The main results appear in [4] and further applications are in [5], [6] and [7]. Instead of considering network processes per se, we addressed the broader problem of characterizing point processes associated with transitions of a general stationary Markov process. Considering the point process of interest in reverse time and identifying its martingale dynamics, we found a necessary and sufficient condition for it to be a Poisson process. We also present similar characterizations of compound Poisson processes and marked or multi-variate Poisson processes.

A major contribution of [4] is to lay bare the features of the driving Markov process that underlie the Poisson nature of the point processes. The earlier ad hoc approaches using Markov renewal processes and filtering are more indirect and unrevealing. Our approach also applies to point process functionals of non-Markovian processes. We have applied the preceding results to certain service systems with batch arrivals and departures [4] and to the network processes [5] we will discuss next.

3. Stochastic Network Processes

We have been developing a theory of Markovian network processes for modeling networks with a variety of dependencies. Our first major article on this is [5]. This opened up the subject of dependencies in networks by presenting a new type of multivariate distribution for network processes. Prior to this, the theory consisted of two extreme types of processes: reversible network processes and networks with independent nodes and routes (whose equilibrium distribution is of product form). We identified a large class of network processes between these two extremes and described their equilibrium behavior by the multivariate distribution just mentioned. An offshoot of our analysis is a new technique for obtaining equilibrium distributions for networks.

A common dependency in a network is blocking of units flowing into a node when the node is filled to its capacity. Such blocking in networks was the theme of an international conference at North Carolina State University in 1987. One of our major contributions in [5] was to show how to model blocking in certain networks that are not reversible; prior results assumed reversibility or used approximations. We also showed how to handle other types of blocking due to general constraints on a network.

Another topic in [5] is the characterization of Palm probabilities of networks at their transitions. We were the first to show how the general theory of Palm probabilities can be used to solve problems that others have been struggling with using ad hoc arguments (see the report of June 23, 1989 for more details on this and other contributions in [5]).

Encouraged by the results in [5], we started to characterize the equilibrium behavior of several new network processes. We noticed that these processes and the few other ad hoc models of others all satisfied a certain "partial balance" property. Upon further study, we discovered a general form for the equilibrium distribution of partially balanced networks. We also found a necessary and sufficient condition for a process to be partially balanced. These findings are documented in [9], the Ph.D. dissertation of Kook (see the June 23, 1989 report); we are currently preparing papers on this.

4. Travel Times in Networks

What is known about travel times of units in queueing networks? For a classical Jackson network with the additional assumption that units cannot overtake each other, the total sojourn time of a unit in a set of nodes is the sum of independent exponential sojourn times at the nodes visited. This is essentially the extent of our knowledge of travel times. The problem is that, without the overtake-free assumption, which is very restrictive, the single sojourn times of a unit at the nodes are typically not independent or exponentially distributed. Consequently, the total sojourn time in a set of nodes is generally intractable.

There are a variety of travel times in networks, in addition to sojourn times in sets of nodes, that are important for assessing the quality of a network. Two examples are the time for a unit to go from one set of nodes to another set, and the time that a unit spends as a certain type (or class) during its stay in a set of nodes. Such passage times are the focus of [9], (which should be completed in a few weeks). We introduce a general notion of a "route" that units may take in a network. The "passage time" for a route is the time it takes for a unit to travel the route. We consider a variety of passage times for general Markovian queueing networks in which units may overtake one another. Our main results are expressions for the means, and in some cases, higher moments and Laplace transforms of these sojourn and passage times. The difficulty is that it is not known whether a unit is undergoing a passage on a route until the route is completed. In other words, the number of units undergoing a passage at any time is a function of the future of the network process as well as its past. We overcome this difficulty by a subtle labeling device that helps us look into the future in a regenerative sense. The results in [9] solve a long-standing problem.

5. A New Look at Renewal Theory

Our study of the convergence of performance parameters of networks prompted us to try to apply the key renewal theorem to novel settings. In doing so, we had to address and solve a few basic problems dealing with an expanded use of this theorem to non-traditional settings. This resulted in the paper [8]. The key points we made are as follows:

- The renewal equation is not needed for applying the key renewal theorem. Standard texts by Feller and others stress that this is the first step one takes in each application. We now know this is not needed.

- We extend the use of the renewal theorem to certain stationary and crudely regenerative phenomena not covered before.

- We found some refinements on classical limit theorems for Markov processes.

6. Miscellaneous Information

Most of the graduate student support on this research was given to Dr. Kwangho Kook (from Korea) and several years ago some funds were given to Mr. Ronald Menich (from USA). Their dissertations are listed below. Dr. Kook's dissertation received a prize for being the best one in 1989 form our school of ISyE - about 10 were considered seriously.

You asked about honors we received lately. I haven't received any showy ones, but have received implicit recognition as follows:

(i) Was appointed as area editor in 1990 of stochastic systems for Mathematics of Operations Research (previous area editors were Donald Iglehart, Erhan Cinlar and Ward Whitt).

(ii) Visited the International Banach Center in Warsaw in April 1990. Gave special 4-hour talk on network processes at conference on applied probability (this was the first such conference on this mathematical topic). This center, which is run by the Eastern European countries, including the USSR, is comparable to the center at Oberwolfach in Germany, which hosts mathematical workshops continuously.

(iii) Was keynote speaker at the 5th Biannual Meeting in September 1989 on the Modeling of Computer Systems In Braunschweig sponsored by German Computer and Mathematical Sciences.

(iv) Was on NSF panel in 1988 for mathematical sciences for the Science and Technology Program designed to fund major centers.

(v) Wrote major chapter for Operations Research Handbook on Stochastic Models (see the enclosed advertisement).

Papers by R. F. Serfozo in 1988-1990

[1] Extreme values of birth and death processes and queues, Stoch. Processes Appl. 27, 291-306, 1988.

[2] Extreme values of queue lengths in M/G/1 and G/M/1 systems, Math. Oper. Res. 13, 349-357.

[3] Joint with Chin, K.E., Networks of queues with blocking and load balancing, Current Research in the Movement, Storage and Control of Material, Vol. I, Springer-Verlag, 1989.

[4] Poisson functionals of Markov processes and queueing networks, Adv. Appl. Probability 21, 595-611, 1989.

[5] Markovian network processes; congestion-dependent routing and processing, Queueing Systems, 5, 5-36, 1989.

[6] Joint with Kook, K., Mean passage times in queueing networks, Proceedings of Fifth GI-ITG Conference on Measurement, Modeling and Evaluation of Computer Systems and Networks, Springer-Verlag, 1-15, 1989.

[7] Point Processes. Chapter 1 (pp. 1-93) in Stochastic Models (a handbook for Operations Research and Management Science; see the attached advertisement).

[8] Applications of the key renewal theorem: crude regenerations. Submitted for publication 1990.

[9] Joint with Kook, K., Travel times in stochastic networks. Should be completed in June 1990.

Ph.D. Dissertations Associated With Research Contract

Mr. Kwangho Kook (1989). Equilibrium Behavior of Markovian Network Processes. (He is a native of Korea and returned in 1989 to work at Korea's equivalent of AT&T Bell Laboratories).

Mr. Ronald Menich (1990). Resource and Tool Provisioning in Manufacturing Networks. This will be completed in June. (He is an American citizen.)